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Response of Tall Fescue, Bush Bean, and
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Response of Tall Fescue, Bush Bean, and Maize to Chrome Tannery Sludge in Soils

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ABSTRACT

Tannery sludge was compared with commercial nitrogen fertiliser to investigate its potential use as an alternative to commercial fertiliser. Soils containing 38% and 7% organic carbon and with nitrogen contents of 1.3% and 0.2%, respectively, were amended with either commercial N fertiliser or tannery sludge which contained 1.6% chromium. Part of the tannery waste was supplemented with additional chromium (Cr^{3+}) salt before being added to the soils. Tall fescue, bush bean, and maize were grown in the sludge-treated soils and their tops harvested. First harvest yields of dry matter increased when tannery sludge was added to the soil, although less than with commercial N addition. Yields from subsequent harvests were larger from soils amended with tannery sludge.

Yields of bush beans, maize, and tall fescue will increase when tannery sludge is added to soils; however, benefits of the sludge will depend upon: (1) nitrogen status of the soil; (2) organic content of the soil; (3) salt and Cr content of the tannery waste; (4) plant species; and (5) soil pH reaction.

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INTRODUCTION

In 1976, tanneries in the United States were generating more than 32 000 tonnes of dry, potentially hazardous solid waste material each year from chromium-mediated leather tanning operations (Conrad *et al.*, 1976). Conrad *et al.* (1976) predicted that by 1983 this quantity would have increased to 43 400 tonnes. Essentially all the hazardous materials produced during the hair removal and tanning operation are contained in the waste matter stream.

Tannery waste routinely has been disposed of in dumps, landfills, trenches, lagoons, pits, or ponds (Conrad *et al.*, 1976). Since elements associated with human health concerns, e.g. chromium, zinc, lead, copper, nickel and cadmium, are found in tannery sludge (Conrad *et al.*, 1976; Wickliff *et al.*, 1982), disposal sites must be managed carefully either to eliminate percolation water or to ensure that the water does not contain trace elements that may be hazardous to vegetation and/or human health. Because of water quality problems associated with routine methods of tannery waste disposal, land application of the sludge is being investigated as an alternative.

Wastewater sludges from facilities which use the Cr tanning procedure contain nitrogen and liming materials that may benefit agriculture. However, in contrast to the N and lime benefits, Cr salts may inhibit plant growth (Mortvedt & Giordano, 1975; Wallace *et al.*, 1976; Kick & Braun, 1977). Trivalent Cr (Cr^{3+}) appears to be the element in tannery waste in sufficient concentration to be toxic to plants and animals; thus it may be an appropriate guide to regulating the application rates of tannery sludge (Conrad *et al.*, 1976; Wickliff *et al.*, 1982). Because of the Cr salt, the sludge must be applied to agricultural soils with care and the resulting effects must be thoroughly investigated before specific recommendations for use are possible.

Tannery sludge containing Cr^{3+} was added to a loessial soil low in organic matter, a gleyed loam soil, and an acid sandy soil to determine the effects on growth, yield and Cr content of spring rye, Serradella, green mustard, winter rye, winter wheat, spinach and ryegrass (Kick & Braun, 1977). After the sludge was applied, the Cr concentration in the soil ranged from 80 to 2884 mg kg^{-1} . When the Cr concentration exceeded 500 mg kg^{-1} and the pH was below 6.0, growth of all plant species tested decreased. When lime was applied to the loessial and loam soils so that the pH exceeded 6, the Cr toxicity threshold was raised to 1000 mg kg^{-1} . The

Cr content in the grain from winter wheat and winter and spring rye was not influenced by Cr in the soil (Kick & Braun, 1977). In contrast, the Cr content of the mustard, ryegrass and spinach increased with the higher soil Cr level. The Cr extracted from the soil by ammonium acetate increased with Cr application and was proportional to uptake of elements by mustard, ryegrass and spinach.

The investigation reported here was designed to determine the toxic and/or beneficial effects on plant growth when tannery sludges containing Cr are added to soils. This study deals with a glasshouse experiment on the growth response and nutrient and trace element accumulation by maize, tall fescue and bush beans when tannery sludge was added to two acid soils, one low and the other high in organic matter. The reactions of these soils to chrome tannery sludge have been reported by Wickliff *et al.* (1982).

METHODS

Preparation of soil mixtures

Amity silty clay loam (7% organic C) and Semiahmoo muck (38% C) soils were limed at the rates of 12 and 48 tonnes ha⁻¹ of calcium carbonate, respectively (Wickliff *et al.*, 1982). The limed soils were allowed to equilibrate for six weeks and then air-dried. Samples of the soils were amended with tannery sludge at rates equivalent to one-half, one and two times the normal agricultural application of available nitrogen for tall fescue, maize and bush bean crops.

Prior to planting, the acid and limed Amity soils were amended with commercial nitrogen fertiliser, (NH₄)₂SO₄, at rates one-half, one and two times the amount required for normal crop growth (Wickliff *et al.*, 1982). No commercial fertiliser was added to the Semiahmoo muck because it contained N in quantities equivalent to or greater than that required for normal crop growth.

Tannery sludge from the S. B. Foot Tanning Company, Redwing, Minnesota, was dried for 24 h in a forced draft oven at 50°C, pulverised in a hammer mill, and sieved to pass a 2-mm screen. Analytical characterisation of the dry sludge and soils was previously reported (Wickliff *et al.*, 1982). Portions of the tannery sludge were mixed with sugar-reduced basic chromium sulphate (Cr³⁺), the compound used in the chrome-tanning operations (Wickliff *et al.*, 1982). This compound

was added to the tannery sludge so that the final Cr concentration was 10 and 100 times the initial Cr concentration of the sludge. These Cr-supplemented wastes were applied to the two soils using N as the guide element.

The soil mixtures were placed in polyethylene pots (3.78 litres) and kept in a glasshouse without further addition. The sides and bottom of each pot were covered with opaque plastic to exclude light and prevent algal growth. During the summer, the plastic was covered with aluminium foil to reflect sunlight and maintain soil temperatures at ambient glasshouse level. Glasshouse temperatures were kept at 24°C during the day and 18°C at night. Natural light was supplemented with sodium vapour lamps, about 11 000 lux, and a 16-h photoperiod was maintained. Water was added as necessary to maintain soil moisture at 50% field capacity (Reuss *et al.*, 1978). All treatments were replicated four times.

Sample collection

The number of seeds planted per pot were 12 tall fescue *Festuca arundinacea* L., six hybrid maize *Zea mays* L. cv. Jubilee, and six bush bean *Phaseolus vulgaris* L. cv. Blue Lake 53. After emergence, the plants were counted to determine the germination and plant establishment. After establishment, the maize and bush bean seedlings were thinned to two plants per pot. No tall fescue seedlings were removed.

The maize and bush beans were harvested 42 and 49 days after planting, respectively. The tall fescue was harvested on days 73, 146 and 292 after planting. At harvest, two replicates of the foliage of each crop were combined for chemical analysis. Plant material was dried for 24 h in a forced draft oven at 70°C, ground in a Wiley mill, and stored for analysis.

Soils in which the maize and bush bean plants were grown remained fallow for nine weeks after the first harvest, then were replanted, measured, and harvested as before. Soil moisture was maintained at 50% field capacity. After the soils had remained fallow for another nine weeks, the planting and harvesting procedures were repeated a third time.

Chemical analysis

The plant samples were digested with nitric and perchloric acids; then chromium, micronutrients, and contaminating trace elements were

TABLE 1
Seedling Emergence from Soils Treated with Tannery Sludge (LSD, Least Significant Difference)

Tannery sludge ^a (tonnes ha ⁻¹)	N ^b (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr ^c (g kg ⁻¹)	% Emergence								
				Bean			Maize			Fescue		
				Planting			Planting			Planting		
				1	2	3	1	2	3	1	2	3
<i>Amity silty clay loam</i>												
	0			68	97	100	90	95	89			69
	0.5N			83	97	90	100	95	95			88
	1N			75	97	92	52	95	92			82
	2N			85	95	95	90	95	77			84
0.5W				83	95	95	95	97	95			90
1W				80	100	92	62	97	95			70
2W				78	95	92	70	97	90			80
1W			10X	42	92	100	88	97	97			59
1W			100X	0	0	0	0	0	0			0
	0	12.3		58	97	95	95	97	97			74
	2N	12.3		10	95	95	95	100	90			83
2W		12.3		35	92	100	98	95	95			83
2W		12.3	100X	0	0	0	0	0	0			0
<i>Semiahmoo muck</i>												
0				63	92	97	95	82	96			76
0.5W				95	97	95	88	90	100			87
1W				90	92	97	95	95	92			77
2W				85	95	95	70	97	97			82
1W			10X	85	92	100	63	100	97			92
1W			100X	23	77	72	30	32	72			0
0		47.7		73	92	90	92	95	100			84
2W		47.7		88	90	97	98	100	100			82
2W		47.7	100X	68	80	95	85	70	87			83
LSD (5%)				14	17	14	18	19	15			13

^a W, 13, 23 and 21 tonnes tannery sludge ha⁻¹ for bush bean, maize and tall fescue, respectively. These application rates provide the N equivalents of the quantities of N in commercial fertiliser required for normal growth of the given crops.

^b N = 110, 200 and 180 kg nitrogen ha⁻¹ for bush bean, maize and tall fescue, respectively. N refers to the amount of commercial nitrogen fertiliser required for normal growth of the given crops.

^c X = 0.09, 0.16 and 0.15 g kg⁻¹ for bush bean, maize and tall fescue, respectively. Chromium was added to tannery sludge at 10 and 100 times the initial Cr concentration in the sludge.

determined using the inductively coupled plasma emission spectrometer (McQuaker *et al.*, 1979). On the same digest, calcium, magnesium and potassium concentrations were measured with an atomic absorption spectrophotometer. Sulphur was determined by turbidimetric sulphate determination (Franson, 1976), which had previously been validated with standard plant samples.

The total phosphorus and nitrogen concentration of each plant sample was established using a modified Kjeldahl procedure in which dry potassium sulphate, mercuric oxide and concentrated sulphuric acid were reacted with the plant tissue (Franson, 1976). This method had also been validated previously with standard plant samples. The total N and P concentration of each solution was determined colorimetrically with a Technicon Autoanalyzer (Gales & Booth, 1974).

Statistical analysis

In experiments with data reported later (in Tables 2, 3, 5 and 7), treatment means often varied greatly with treatment standard deviations increasing proportionally. Therefore, yield and analytical data were transformed to their respective common logarithms for statistical analysis (Steel & Torrie, 1960). Each determination recorded in Tables 2, 3, 5 and 7 is the geometric mean of two samples (see 'Sample collection'). A least significant percentage (LSP), which gives the percentage increase of the larger geometric mean over the smaller one required for statistical significance, was included in the tables. The smaller mean is subtracted from the larger mean and the difference is divided by the smaller mean. The quotient is multiplied by 100%. The result must be larger than the corresponding LSP in order for the difference to be statistically significant. Each LSP value in the tables is then a percent of the smaller mean. A least significant difference (LSD) was computed without log transformation because the data were recorded as percent values (Table 1).

RESULTS AND DISCUSSION

Seedling emergence

The percent seedling emergence exceeded 75% for tall fescue and bush bean in both soils amended with either commercial fertiliser or tannery

sludge (Table 1). Adding tannery sludge or commercial N increased the tall fescue seedling emergence over the untreated Amity soil. This increase was also observed in the bean seedling establishment after the first planting in both soils. Unexpectedly, application of lime reduced the bean seedling emergence in the Amity soil; maximum reduction occurred when both lime and fertiliser were added. Percent emergence of maize seedlings after the first planting decreased when the recommended rate of commercial N was added to the Amity soil (Extension Service, 1978), but not at higher or lower rates. This cannot be explained in terms of traditional effects of fertiliser application to soils. Percent maize seedling emergence also decreased in the Amity soil which received the two highest rates of tannery sludge.

Addition of the Cr salt markedly reduced bean and fescue seedling establishment in Amity soil at both Cr application rates; however, the effect decreased with subsequent plantings. Establishment of maize seedlings was reduced only at the highest rate of Cr application. In contrast to the Amity soil, the addition of Cr to the Semiahmoo soil at the 10X rate generally did not affect seedling emergence; however, when the Cr was added at the 100X rate, emergence was inhibited for all crops (Table 1). Adding lime and tannery waste increased seedling emergence. The effect of the 10X Cr salt on seedling establishment was observed only during the first bean and maize planting.

Tall fescue

Yield

Addition of either tannery sludge or commercial N increased first harvest yields of tall fescue; however, yields from plants grown on sludge-treated Amity soil were less than those from plants treated with commercial N (Table 2). The numerous factors associated with the tannery waste amendment of soils make these data difficult to interpret. The first harvest yields in sludge-amended soil may have been reduced because of a lack of N or other nutrients available for plant uptake. It is also possible that fescue growth is inhibited by waste constituents such as Cr and/or total salt content (Wickliff *et al.*, 1982).

The dry weight of tall fescue did not decrease in the Amity soil containing 1.4 g Cr kg⁻¹ dry soil. This Cr treatment did, however, decrease the first harvest yield of tall fescue in the Semiahmoo soil (Table 2). Addition of the 15 g Cr kg⁻¹ soil treatment to the limed Semiahmoo

TABLE 2
Yield of Tall Fescue Grown on Soil Amended with Tannery Waste (LSP, Least Significant Percent Difference)

Tannery sludge (tonnes ha ⁻¹)	N (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr (g kg ⁻¹)	Dry weight (g pot ⁻¹)			
				Harvest			Total
				First	Second	Third	
<i>Amity silty clay loam</i>							
	0			0.6	0.1	3.9	4.6
	90			10.5	1.6	4.7	16.8
	180			17.2	4.2	6.2	27.6
	360			28.4	9.9	6.7	45.0
10.6				4.1	1.8	4.9	10.8
21				12.8	4.5	9.5	26.8
42				22.6	16.1	18.2	56.9
21			1.4	0.7	0.5	9.4	10.6
21			15	a	a	a	a
	0	12		7.7	6.4	10.8	24.9
	360	12		28.1	14.7	10.1	52.9
42		12		13.3	12.1	15.7	41.1
42		12	15	a	a	a	a
<i>Semiahmoo muck</i>							
0				15.3	4.0	8.5	27.8
10.6				17.3	7.5	9.3	34.1
21				20.4	11.5	14.4	46.3
42				25.7	16.5	21.7	63.9
21			1.3	4.9	3.9	9.0	17.8
21			15	a	a	a	a
		48		17.0	6.2	11.6	34.8
42		48		22.5	12.1	21.2	55.8
42		48	15	0.9	4.4	11.3	16.6
	LSP (5%)			77	77	20	15

* No seedlings emerged.

soil decreased plant dry weight 94% below that of plants which were grown on the limed Semiahmoo soil. It cannot be concluded that these effects are due to the high Cr concentration alone because the increased electroconductivity and decreased pH could also adversely affect dry matter yields (Wickliff *et al.*, 1982).

Fescue yields at the second and third harvests increased with tannery sludge application to the Amity soil; yields were greater with plants grown on the sludge-amended soils than on those amended with commercial N fertiliser (Table 2). Yields increased most with the highest rate of tannery sludge addition to the Amity soil. This probably occurred because nitrogen available for plant uptake decreased in soil amended with

commercial fertiliser, while in soils amended with the tannery waste, N or another mineralisable nutrient element continued to support growth. Although mineralisation in soils decreases when tannery sludge is added, significant mineralisation activity continues (V. V. Volk, details to be published). Thus, sufficient mineralisation of organic nitrogenous constituents would have occurred to support plant growth. In fact, the concentration of 2M KCl extractable nitrate plus nitrite N increased 374% in soil cropped to tall fescue that received the highest rate of tannery sludge application (Wickliff *et al.*, 1982). However, in the waste there may have been chelation of trace elements toxic to plants, thus decreasing their growth-inhibiting effects.

The second and third harvests of fescue grown on the Amity soil amended with tannery sludge plus the 1.4 g Cr kg^{-1} soil treatment were greater than those of comparable plants grown on non-amended Amity soil (Table 2). A possible explanation is that the available Cr decreased in the Cr-treated soils, while the available N remained high (Wickliff *et al.*, 1982).

At the second and third harvests, the yield of fescue grown on the Semiahmoo soil increased with tannery sludge application (Table 2). Addition of the 1.3 g Cr kg^{-1} soil treatment plus tannery sludge did not reduce yields in comparison with control plants. At the third harvest, the dry weight of the fescue grown on limed Semiahmoo soil was the same as that of some plants grown on the same soil amended with sludge containing the 15 g Cr kg^{-1} soil treatments. The latter group of plants also weighed more than plants grown in non-amended acid Semiahmoo soil. These results are difficult to interpret because the same plants were harvested each time after re-growth; therefore, selection of Cr-tolerant strains did not occur. Some investigators have reported stimulatory effects of Cr on plant growth (Bertrand & de Wolf, 1965, 1968; Bertrand & Vinchon, 1964). However, Cr is not considered an essential micronutrient (Hewitt & Smith, 1975). At the third harvest, dry matter yields were inhibited to a smaller extent by the 1.4 and 1.3 g kg^{-1} Cr applied to the Amity and Semiahmoo soils, respectively, than was the case in the two previous harvests. Third harvest yields were also inhibited to a smaller extent by the 15 g kg^{-1} Cr applied to the Semiahmoo soil with carbonate.

First harvest—element composition

When commercial N fertiliser was added to the Amity soil, the nitrogen, phosphorus and sulphur concentration of tall fescue increased at the first

TABLE 3
Chemical Analysis of the First Cutting of Tall Fescue Grown on Tannery-Sludge-Amended Soils (LSP, Least Significant Percent Difference)

Tannery sludge (tonnes ha ⁻¹)	N (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr (g kg ⁻¹)	Macronutrients (g kg ⁻¹)				Micronutrient and trace elements (mg kg ⁻¹)									
				N	P	S	Ca	Mg	K	B	Cr	Cu	Fe	Mn	Zn		
<i>Amity silty clay loam</i>																	
	0			15	3.1	1.7	5.4	3.5	30	10	1.8	<10.2 ^a	99	443	18		
	90			11	1.0	1.2	4.1	2.9	28	9	1.4	<9.9 ^a	44	265	12		
	180			17	1.2	1.6	3.6	2.9	45	7	1.8	<9.5 ^a	56	246	16		
	360			21	1.6	1.9	4.2	3.2	43	7	^b	<10.0 ^a	58	248	17		
10.6				14	2.2	2.6	5.8	3.5	34	11	1.8	<9.8 ^a	43	167	16		
21				12	1.6	1.8	4.8	2.9	30	11	1.7	<9.4 ^a	41	66	12		
42				18	1.2	2.0	7.5	3.9	26	18	1.5	4.6	41	95	13		
21			1.4	19	0.8	3.2	3.8	1.5	22	<2 ^a	2.0	5.0	^b	575	10		
	0	12		12	2.4	2.2	4.9	3.3	25	11	2.3	5.0	32	41	10		
	360	12		23	1.1	2.4	6.2	3.6	34	11	3.0	6.9	72	63	13		
42		12		21	1.3	2.1	7.0	3.4	34	15	3.2	7.7	49	180	18		
<i>Semiahmoo muck</i>																	
0				14	3.9	1.9	3.5	2.4	33	8	1.6	<9.9 ^a	45	114	17		
10.6				16	4.2	2.4	4.6	3.2	39	9	2.0	<9.7 ^a	46	47	20		
21				16	3.7	2.0	5.1	3.2	48	13	2.3	<9.5 ^a	46	22	22		
42				20	3.3	2.2	5.4	3.6	40	11	2.4	5.2	38	16	23		
21			1.3	12	3.4	2.0	5.2	2.5	33	11	2.5	5.5	31	144	23		
		48		16	3.6	2.1	4.6	2.6	32	10	2.5	4.5	35	7	13		
42		48		21	3.1	2.3	6.1	3.6	48	12	4.7	8.3	43	23	23		
42		48	15	30	2.6	3.3	1.9	2.0	31	14	5.5	8.2	85	32	32		
	LSP (5%)			17	24	19	9	16	26	59	20	20	28	79	30		

^a Sample size too small for accurate analysis.

^b Not analysed.

cutting, after first decreasing (Table 3). It was often observed that, as higher yields were obtained, the content of these three elements was reduced when the plants were grown on soil treated with the lowest rate of N, compared with the control pots, because they were diluted in the plant.

Application of the tannery waste did not affect the N concentration of tall fescue grown on the Amity soil, but it did slightly increase the N content of fescue grown on the Semiahmoo soil (Table 3). In Amity soil, the highest N in the plant tissue was obtained when lime was added in addition to supplemental N. The P in tall fescue decreased in plants grown on the Amity soil with added tannery sludge and lime (Table 3). Generally, P concentrations in plant tissues are considered adequate at 0.2% (Table 4) (Epstein, 1972). However, in the Amity soil, many plants contained less, denoting a possible P deficiency. All plant samples taken from the Semiahmoo soils exceeded 0.2% phosphorus.

The calcium and magnesium concentrations of the tall fescue increased with application of the tannery waste to Semiahmoo soil (Table 3). Lime increased the Ca; the highest concentration occurred when both lime and tannery sludge were applied to the Semiahmoo soil. Adding supplemental Cr salt reduced both the Ca and Mg content of tall fescue.

No significant changes were observed in first harvest boron or potassium concentrations in tall fescue from waste- or fertiliser-amended soils (Table 3). Internal B concentrations are generally considered adequate at 20 mg kg⁻¹ in dry plant material (Epstein, 1972; Salisbury & Ross, 1969). All first harvest B concentrations were below this level, although no symptoms of B deficiency were observed in these plants. Grasses apparently require very little boron in comparison with other plant genera (Russel, 1957).

The cadmium, lead and nickel concentrations of tall fescue were usually below the detection limits of the equipment used. Where the concentrations of these elements were high enough to be accurately measured, Cd ranged from 1.5 to 3.0 mg kg⁻¹ dry plant material, Pb 17 to 30 mg kg⁻¹, and Ni 5.4 to 7.4 mg kg⁻¹. These concentrations were below the 9, 100 and 50 mg kg⁻¹ levels for Cd, Pb and Ni, respectively, levels which are generally considered toxic to plants (Table 4).

The chromium content of the tall fescue in the Amity soil decreased slightly with tannery sludge application (Table 3). After adding lime, the Cr content increased and the highest concentration occurred when the lime was supplemented with the waste product. The Cr content of tall

TABLE 4
Typical Concentrations of Mineral Elements in the Dry Foliage of Normal Plants (Hewitt & Smith, 1975) and in the Foliage of Plants Exposed to Chemical Elements Considered Toxic

Element	Concentrations in dry foliage (mg kg ⁻¹ or g kg ⁻¹)		References to elements considered toxic to plants
	Normal	Toxic	
	(mg kg ⁻¹)		
Cu	5-15	> 15	Walsh <i>et al.</i> (1972), Wallace & Mueller (1973), Dragun <i>et al.</i> (1976)
Fe	50-300	> 1 320	Brown (1976)
Mn	25-250	> 300	National Research Council Committee (1973)
Zn	15-75	> 400	Chapman (1966)
B	15-100	> 250	Brown (1976)
Cr	0.1-1.0 ^a	> 8	Allaway (1968), Huffman & Allaway (1973), National Research Council Committee (1974)
Cd	0.2-0.8 ^a	> 9	Allaway (1968), Jastrow & Koeppe (1980)
Pb	5.7-11.0 ^a	> 100	National Research Council Commission (1972)
Ni	0.1-5.0 ^a	> 50	Bazzaz <i>et al.</i> (1975) National Research Council Committee (1975)
	(g kg ⁻¹)		
N	15-35	^b	
P	1.5-3.0	^b	
S	1.0-3.0	^b	
Ca	10-50	^b	
Mg	2.5-10.0	^b	
K	15-50	^b	

^a Nutrient value not established.

^b Not considered toxic to plants.

fescue grown on the Semiahmoo soils increased with sludge application and increased again when lime was applied concurrently with the waste. The highest Cr content was obtained when the soil was limed and treated with tannery sludge and supplemental Cr.

The copper concentrations in the tall fescue were not significantly different as a function of commercial fertiliser, tannery sludge or lime applications (Table 3). The iron concentration in the Amity soil which did not receive these additions was greater than in all other soils except the Semiahmoo which received 15 g kg^{-1} Cr.

The manganese concentrations of the tall fescue grown on the Amity soil decreased when commercial N was added (Table 3). The concentrations were lowest upon the application of the two higher rates of tannery sludge and when plants were grown on the lime-amended soil. These concentrations reflected the diethylenetriamine penta-acetic acid (DPTA) extractable manganese content of the soil before cropping (Wickliff *et al.*, 1982). Adding supplemental Cr increased the Mn in the tall fescue.

When waste material was added to the Semiahmoo soil, the Mn content of the tall fescue decreased to levels well below those considered adequate for normal plants (Table 3) (Epstein, 1972). Adding supplemental Cr increased the Mn when the Cr was added at the 1.3 g kg^{-1} level, probably because the extractable Mn content of the soil increased when it became more acidic after Cr was added (Wickliff *et al.*, 1982).

Second harvest—element composition

At the second cutting, the average concentration of nitrogen in tall fescue was generally about 50% lower than that observed in the first harvest (Table 5); it varied with the extractable N in the soil (Wickliff *et al.*, 1982) rather than with initial tannery sludge or N applications. All N concentrations were below the 15 g kg^{-1} expected in normal plants (Table 6). A possible nitrogen deficiency is suspected in the tall fescue regardless of soil or amendment. The N, P and S concentrations decreased in fescue grown in the Amity soil which received either tannery sludge or commercial N fertiliser.

The magnesium concentrations decreased in plants in Amity soil which had received only the tannery waste; the calcium concentrations decreased after first increasing (Table 6). The concentrations of Fe and Cu decreased in plants grown in Amity soil which received only commercial N fertiliser; the concentrations of Mn and Zn decreased after first

TABLE 5
Percent Change in the Selected Element Content of Tall Fescue Relative to the First Harvest

Tannery sludge (tonnes ha ⁻¹)	N (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr (g kg ⁻¹)	N			P			S			Ca			K			Cr			Mn			
				Harvest			Harvest			Harvest			Harvest			Harvest			Harvest			Harvest			
				2	3		2	3		2	3		2	3		2	3		2	3		2	3		2
Amity silty clay loam																									
	0			-37	-58	0	19	24	*				33	-7	-56	-80	-5	22	55	-9					
	90			-43	-49	60	230	200	200				90	59	-53	-71	14	229	379	*					
	180			-69	-72	-8	108	43	94				106	92	-71	-78	-17	233	306	*					
	360			-76	-78	-50	-6	-47	21				19	95	-70	-74	*	*	195	*					
10.6				-45	-59	104	200	150	73				43	28	-53	-76	17	222	83	66					
21				-45	-49	131	281	178	178				63	25	-50	-66	11	270	148	127					
42				-64	-69	50	275	25	70				-13	-1	-54	-69	47	313	119	180					
21			1.4	-83	-61	113	163	44	28				21	3	-27	-64	50	925	139	*					
	0	12		-44	-52	58	0	-5	0				59	0	-52	-68	-13	78	49	0					
	360	12		-77	-79	-18	200	4	21				31	11	-74	-74	-23	77	16	27					
42		12		-61	-70	69	169	43	62				26	*	-59	-71	-22	63	144	182					
Semiahmoo muck																									
0				-59	-55	69	146	26	42				114	83	-70	-79	0	81	689	278					
10.6				-64	-59	0	83	21	79				53	43	-73	-79	-25	180	360	362					
21				-65	-66	0	100	40	70				22	25	-73	-83	-22	143	327	391					
42				-66	-72	-21	72	-14	23				64	33	-68	-80	-16	162	275	438					
21			1.3	-39	-60	-3	50	90	85				44	37	-55	-82	-28	212	314	*					
		48		-58	-59	3	94	5	5				71	48	-69	-75	-20	60	843	357					
42		48		-68	-75	-19	48	-4	17				28	64	-75	-85	-45	10	222	396					
42		48	1.5	-73	-78	-46	-46	21	94				26	42	-58	-74	-31	96	294	722					

* Not calculable.

TABLE 6
Chemical Analysis of the Second Cutting of Tall Fescue Grown in Tannery Sludge Amended Soils (LSP, Least Significant Percent Difference)

Tannery sludge (tonnes ha ⁻¹)	N (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr (g kg ⁻¹)	Macronutrients (g kg ⁻¹)					Micronutrient and trace elements (mg kg ⁻¹)						
				N	P	S	Ca	Mg	K	B	Cr	Cu	Fe	Mn	Zn
Amity silty clay loam															
	0			9.4	3.1	2.1	7.2	6.2	13	<24 ^a	1.7	4.6	58	689	15
	90			6.3	1.6	3.6	7.8	6.6	13	<25 ^a	1.6	4.2	39	1271	19
	180			5.2	1.1	2.3	7.4	4.6	13	<24 ^a	1.5	3.7	26	999	14
	360			5.1	0.8	1.0	5.0	3.4	13	<25 ^a	1.4	3.0	26	732	9
10.6				7.7	4.5	6.5	8.3	5.7	16	<24 ^a	2.1	4.3	87	305	15
21				6.6	3.7	5.0	7.8	5.1	15	<25 ^a	1.9	4.3	37	164	16
42				6.5	1.8	2.5	6.5	4.5	12	<24 ^a	2.2	4.6	138	208	12
21			1.4	3.3	1.7	4.6	4.6	3.1	16	<24 ^a	3.0	5.0	61	1373	12
	0	12		6.7	3.8	2.1	7.8	5.2	12	<25 ^a	2.0	4.3	51	61	16
	360	12		5.4	0.9	2.5	8.1	4.5	9	<25 ^a	2.3	4.6	20	73	20
42		12		8.2	2.2	3.0	8.8	5.1	14	<25 ^a	2.5	5.2	49	439	^a
Semisthmo muck															
0				5.8	6.6	2.4	7.5	7.3	10	36	1.6	3.4	48	899	19
10.6				5.8	4.2	2.9	7.0	5.9	11	<24 ^a	1.5	3.8	17	216	19
21				5.6	3.7	2.8	6.2	5.6	13	<25 ^a	1.8	3.7	34	94	18
42				6.9	2.6	1.9	8.9	6.3	13	<26 ^a	2.0	3.9	23	60	18
21			1.3	7.3	3.3	3.8	7.5	5.3	15	<25 ^a	1.8	4.8	24	596	26
		48		6.8	3.7	2.2	7.9	6.0	10	<25 ^a	2.0	4.4	23	66	15
42		48		6.8	2.5	2.2	7.8	5.1	12	<26 ^a	2.6	4.8	21	74	17
42		48	15	8.0	1.4	4.0	2.4	2.2	13	<29 ^a	3.8	5.0	49	126	14
	LSP (5%)			13	25	24	29	19	29	^a	29	15	147	32	30

^a Sample size too small for accurate analysis.

^b Not analysed.

increasing. The concentrations of Mn and Ca remained higher than the typical concentrations in plants, while the concentrations of Fe, Cu and Zn fell below these values (Table 4) after the soil amendments. Only the concentration of Mg remained within the range of normal concentrations. The P and Mn concentration decreased in plants grown on the Semiahmoo soil with tannery sludge added but levels remained higher than the minimum considered normal in plants (Table 4).

After the second harvest, concentrations of the micronutrient and trace elements in the tall fescue generally varied with the extractable element contents in the soil (Table 6) (Wickliff *et al.*, 1982). The concentrations of boron were below the detection limits of the analytical instruments; therefore, no conclusions can be drawn concerning B. Increases in the concentration of chromium in plants grown on limed soil did not relate to either total or extractable soil Cr levels (Wickliff *et al.*, 1982).

Third harvest—element composition

In the third fescue cutting, nitrogen and potassium concentrations in the plants decreased further (Table 5). When both $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ are available for plant uptake, the internal nitrogen concentration considered adequate for most higher plants is 15 g kg^{-1} (Salisbury & Ross, 1969). However, the concentration in fescue was approximately half this value (Table 7), indicating a possible nitrogen deficiency. The concentration of the other elements appeared adequate or greater because of the smaller plant mass, as measured by dry matter yield, associated with the nitrogen deficiency. The concentrations of P and Cr increased in the third cutting (Table 5); apparent Cr increases may be explained by the smaller plant mass.

The nitrogen and phosphorus concentrations in the third cutting of fescue grown on Amity soil with the highest application of commercial N were less than in plants grown on the untreated Amity soil (Table 7). The highest N concentration in tall fescue occurred in plants harvested from the Amity soil which received the 1.4 g kg^{-1} Cr treatment amended with tannery sludge. This apparent increase in N cannot be explained in terms of decreased plant mass because only those plants receiving the highest rates of tannery sludge, with and without lime, were larger (Table 2). There was less available Cr in the soil at the third cutting although there was no decrease in total Cr (Wickliff *et al.*, 1982).

Phosphorus and boron concentrations were greater in plants grown on the Amity soil which received the two lowest levels of tannery waste than

TABLE 7
Chemical Analysis of the Third Cutting of Tall Fescue Grown on Tannery-Sludge-Amended Soils (LSP, Least Significant Percent Difference)

Tannery sludge (tonnes ha ⁻¹)	N (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr (g kg ⁻¹)	Macronutrients (g kg ⁻¹)						Micronutrient and trace elements (mg kg ⁻¹)						
				N	P	S	Ca	Mg	K	B	Cr	Cu	Fe	Mn	Zn	
				Amity silty clay loam												
	0			6.2	3.7	<0.9 ^a	5.0	5.0	6	9	2.2	2.7	141	405	14	
	90			5.6	3.3	3.6	6.5	5.4	8	8	4.6	4.3	68	^b	15	
	180			4.7	2.5	3.1	6.9	5.2	10	8	6.0	4.5	103	^b	27	
	360			4.6	1.5	2.3	8.2	4.9	11	9	6.0	4.9	93	^b	20	
10.6				5.8	6.6	4.5	7.4	5.6	8	13	5.8	5.4	183	277	16	
21				6.1	6.1	5.0	6.0	5.3	10	10	6.3	6.6	59	150	12	
42				5.5	4.5	3.4	7.4	5.6	8	9	6.2	5.8	57	266	12	
21			1.4	7.4	2.1	4.1	3.9	3.8	8	12	20.5	6.7	211	^b	16	
	0	12		5.8	5.1	1.0	5.9	5.3	8	7	4.1	6.2	59	62	15	
	360	12		4.9	3.3	2.9	6.9	5.5	9	8	5.3	6.9	63	80	19	
42		12		6.3	3.5	3.4	^b	6.3	10	10	5.2	7.1	73	507	17	
				Semishmoor muck												
0				6.3	9.6	2.7	6.4	4.7	7	13	2.9	3.2	72	431	19	
10.6				6.5	7.7	4.3	6.6	5.2	8	14	5.6	5.6	80	217	14	
21				5.3	7.4	3.4	6.4	5.0	8	14	5.6	5.3	55	108	14	
42				5.6	5.7	2.7	7.2	7.0	8	12	6.3	5.5	51	86	17	
21			1.3	4.7	5.1	3.7	7.1	5.3	6	15	7.8	6.1	64	^b	21	
		48		6.5	7.0	2.2	6.8	4.6	8	10	4.0	6.0	60	32	13	
42		48		5.3	4.6	2.7	10.0	8.6	7	10	5.2	6.6	73	114	26	
42		48	15	6.5	1.4	6.4	2.7	3.5	8	10	10.8	5.9	62	263	14	
LSP (5%)				19	42	40	19	15	17	28	44	19	121	39	48	

^a Sample size too small for accurate analysis.

* Not analysed.

in those from untreated soil; however, P and B decreased with each sludge application (Table 7). The P concentration decreased in those plants grown on the tannery-waste-treated Semiahmoo soil and when supplemental Cr salt was added. This finding is consistent with an earlier study which showed that available P also decreased in this soil (Wickliff *et al.*, 1982).

The concentration of phosphorus was below that considered adequate for normal plant growth (Epstein, 1972) when the highest rate of commercial fertiliser was added to the Amity soil and when the highest rate of tannery sludge plus lime was added to the Semiahmoo soil (Table 7). The concentration of B would be considered inadequate regardless of the soil treatment. No conclusions can be drawn concerning the effect of tannery sludge on boron concentration.

The sulphur increased in plants grown on both soils amended with tannery sludge or commercial fertiliser, but then decreased with additional applications of each treatment (Table 7). Except for the non-amended Amity soil, the S concentrations ranged from 0.1 to 0.6%. The S concentration considered adequate in normal plants is 1.0% (Epstein, 1972). Other reports show that 0.2–0.3% S is adequate for grasses (Metson, 1973). If there is a sulphur deficiency in plants harvested from the non-amended Amity soil, it was overcome by the added tannery sludge.

The calcium, potassium and copper concentrations increased in plants grown in the Amity soil with added commercial N fertiliser (Table 7). Application of Cr salt reduced the Ca concentration; the range was 0.5 to 1.1%, regardless of treatment. These concentrations are well within the range considered adequate for normal plant growth (Salisbury & Ross, 1969). The concentrations of K, however, were typically less than the 1.0% considered adequate for normal plant growth. The only plants with adequate K were grown on the Amity soil amended with 180 and 360 kg ha⁻¹ N, 21 tonnes ha⁻¹ tannery sludge, and 42 tonnes ha⁻¹ tannery sludge with lime (Table 7). The concentrations of Cu ranged from 2.7 to 7.1 mg kg⁻¹. A Cu concentration of 6 mg kg⁻¹ is considered adequate in normal plants (Epstein, 1972); only plants growing on soils amended with either calcium carbonate or tannery sludge contained this much Cu. Therefore, Cu concentrations did not approach the 15 mg kg⁻¹ generally considered harmful to plants (Table 4).

The concentrations of cadmium, lead, and nickel were either near or below the limits of detection for the analytical instruments used.

Detectable Cd ranged from 1.0 to 2.9 mg kg⁻¹ dry plant material, but the variation in concentration was not statistically significant. Similarly, detectable Pb and Ni did not vary significantly with treatment. The concentration of Pb ranged from 15 to 30 mg kg⁻¹, while that of Ni ranged from 6.5 to 9.2 mg kg⁻¹. The highest concentrations of Cd, Pb and Ni were below the 9, 100 and 50 mg kg⁻¹, respectively, generally considered toxic to plants (Table 4). The Cd concentrations in the tall fescue were always lower than the level normally found in plants (Allaway, 1968). Therefore, Cd contamination is unlikely to result from the application of tannery wastes to agricultural land.

As expected, the chromium concentration was greater in plants grown on soils treated with supplemental Cr salt (Table 7). The concentrations of Cr in the tall fescue plants grown on soil without the supplement ranged from 5.2 to 6.3 mg kg⁻¹, below the 8 mg kg⁻¹ generally considered deleterious to plants (Table 4). The chromium concentrations were consistently lower than the levels that reduce dry matter yield (National Research Council Committee, 1974) when no supplemental Cr salt was applied to soils with tannery sludge. The Cr concentrations in plants grown on the Amity soil which was treated only with commercial fertiliser were not significantly lower than those in plants grown on the Amity soil which received corresponding quantities of the tannery waste. The concentrations of Cr in tall fescue leaves reflected the concentration of available Cr in the soils, which were very low without supplemental Cr salt (Wickliff *et al.*, 1982). The only Cr concentrations that would be considered too high occurred in plants on the Amity soil containing 1.4 g kg⁻¹ Cr and in plants on the Semiahmoo soil containing 15 g kg⁻¹ Cr (Table 7).

The manganese concentration decreased in plants grown on the Semiahmoo soil mixed with tannery sludge and it also decreased in plants grown on the limed Amity and Semiahmoo control soils (Table 7). This effect was probably due to reduced availability of Mn, caused by the increased soil pH and reduced solubility of Mn compounds associated with sludge and lime additions (Brady, 1974; Lindsay, 1979).

The internal concentrations of Mn (405 and 431 mg kg⁻¹ in non-amended Amity and Semiahmoo soils, respectively) were considerably higher than the 50 mg kg⁻¹ considered adequate in normal plants (Table 7) (Epstein, 1972). The only plants with Mn concentrations below 50 mg kg⁻¹ were those grown on the Semiahmoo soil amended only with calcium carbonate. For most plants, toxicity symptoms associated with

TABLE 8
Yield of Bush Beans Grown on Soil Amended with Tannery Waste (LSP, Least Significant Percent Difference)

Tannery sludge (tonnes ha ⁻¹)	N (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr (g kg ⁻¹)	Dry weight (g pot ⁻¹)			
				Harvest			Total
				First	Second	Third	
<i>Amity silty clay loam</i>							
	0			2.3	4.0	4.3	10.6
	55			9.0	6.7	4.1	19.2
	100			10.8	6.8	4.9	22.5
	220			14.4	5.9	3.8	24.1
6.5				4.8	5.2	5.1	15.1
13				6.0	6.5	5.8	18.3
26				3.9	6.3	5.6	15.8
13			0.9	^a	2.5	3.5	6.0
13			9	^a	^a	^a	^a
	0	12		3.6	4.5	5.3	13.4
	220	12		2.4	4.9	4.9	12.2
26		12		1.8	4.0	3.7	9.5
26		12	9	^a	^a	^a	^a
<i>Semiahmoo muck</i>							
0				17.5	10.2	1.7	29.4
6.5				21.2	6.6	2.0	29.8
13				21.6	7.4	2.1	31.1
26				20.1	6.0	1.8	27.9
13			0.8	9.6	9.6	1.9	21.1
13			9	0.9	1.3	2.2	4.4
		48		2.2	7.8	1.8	11.8
26		48		2.0	15.4	2.7	20.1
26		48	9	1.7	2.0	1.4	5.1
	LSP (5%)			46	37	52	98

^a No seedlings emerged.

^b Plants did not survive to harvest.

high internal Mn concentrations appear in the range of 200 to 4000 mg kg⁻¹ (National Research Council Committee, 1973). However, no symptoms of Mn toxicity were seen in this experiment. The additions of the tannery waste and/or calcium carbonate, with resulting increase in soil pH reaction and reduced solubility of Mn, tended to decrease internal manganese concentrations to more acceptable levels.

TABLE 9
Yield of Maize Grown on Soil Amended with Tannery Sludge (LSP, Least Significant Percent Difference)

Waste (tonnes ha ⁻¹)	N (kg ha ⁻¹)	CaCO ₃ (tonnes ha ⁻¹)	Cr (g kg ⁻¹)	Dry weight (g pot ⁻¹)			
				Harvest			
				First	Second	Third	Total
<i>Amity silty clay loam</i>							
	0			1.0	1.3	2.7	5.0
	100			7.9	1.9	4.1	13.9
	200			7.0	1.6	2.7	11.3
	400			16.8	1.9	4.2	22.9
11.4				3.2	3.5	4.2	10.8
23				2.5	3.8	5.6	9.0
46				3.0	3.9	4.5	11.1
23			1.5	0.7	2.6	3.1	6.4
23			16	^a	^a	^a	^a
	0	12		3.7	4.4	5.6	13.6
	400	12		5.0	4.4	6.1	15.5
46		12		3.2	3.5	3.5	10.2
46		12	16	^a	^a	^a	^a
<i>Semiahmoo muck</i>							
0				13.3	6.9	3.6	23.8
11.4				12.4	8.8	2.7	24.0
23				15.1	12.1	3.5	30.7
46				11.4	20.3	6.2	37.9
23			1.5	2.8	9.3	3.5	15.6
23			16	^b	0.5	^b	0.5
		48		9.6	10.9	3.2	23.7
46		48		19.3	14.8	4.7	38.7
46		48	16	0.8	1.6	1.2	3.6
	LSP (5%)			40	22	38	16

^a No seedlings emerged.

^b Plants did not survive to harvest.

Bush bean and maize

Bush bean (Table 8) and maize (Table 9) responded to chrome tannery sludge, commercial nitrogen and chromium salt in a manner similar to tall fescue. Therefore, the conclusions drawn from the tall fescue experiments apply to these crops also. Maize dry matter yields responded

to calcium carbonate addition to both soils in a manner similar to tall fescue, but bush bean dry matter yields decreased when lime was added until the soil pH reaction was neutral or slightly basic (Table 8). More bush bean plant growth occurred in the acid soils than in the limed soils, regardless of the other amendments. Bush bean yields are reduced when soils are limed to a pH reaction above 6.5 (Extension Service, 1978). The pH of the limed soils ranged from 6.7 to 7.5 when no Cr salt was added and the pH of soils receiving the tannery waste without lime or additional Cr salt ranged from 5.7 to 6.9 (Wickliff *et al.*, 1982). The response of bush beans to lime in the soils complicated the results and made interpretation of bean yield data difficult.

The trends associated with the element compositions in bush bean and maize plants in response to the various soil amendments were similar to those observed for tall fescue. These results support data obtained with tall fescue responding to the tannery waste and the other additions to organic and mineral soils.

CONCLUSIONS

The addition of tannery sludge to a nitrogen-deficient soil will markedly increase the dry matter yields of tall fescue and maize. The yields of bush bean will increase less. Adding tannery sludge to a soil already containing adequate nitrogen for normal crop growth will also increase the yields of tall fescue and maize; however, the magnitude of the increase is less than that observed with nitrogen-deficient soil. Tall fescue and maize will respond positively when calcium carbonate is added to the soils whereas bush beans either do not respond or respond negatively. Excessive salt and/or Cu in the soil, after the Cr addition, will decrease seedling emergence and dry matter yields and/or prevent germination of the seeds of all three species.

Crop yields will increase when tannery sludge is added to N-deficient soils, to an extent depending upon: (1) the nitrogen status of the soil; (2) soil organic matter content; (3) salt and Cr content of the sludge; (4) soil pH reaction; and (5) species of plant. In this experiment, soils containing 38% and 7% organic carbon with 1.3% and 0.2% nitrogen contents, respectively, were used. The soil pH was 5.5 before any additions were made. Despite a chromium concentration of 1.6% in the tannery waste with an electroconductivity greater than 3 mmho cm⁻¹, 42.4 tonnes ha⁻¹

tannery sludge was added to each soil with no adverse effect on the dry matter yields of tall fescue, bush bean and maize. When supplemental Cr is not added, the concentrations of Cr are not significantly greater in the tops of plants grown on the tannery sludge than those in the tops of plants grown on commercial N. The concentrations of contaminating trace elements are low enough that the foliage appears safe as forage for consumption by livestock.

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